Initial results of a low-frequency 3D-SAR approach for mapping glacier volumes

Henke, Daniel ; Meier, Erich

Originally published at:
Henke, Daniel; Meier, Erich (2011). Initial results of a low-frequency 3D-SAR approach for mapping glacier volumes. In: 9th Swiss Geoscience Meeting, Zürich (CH), 11 November 2011 - 13 November 2011. Swiss Academy of Science (sc | nat), 382-383.

Initial results of a low-frequency 3D-SAR approach for mapping glacier volumes

Daniel Henke, Meier Erich
Remote Sensing Laboratories (RSL), University of Zurich, Winterthurer Strasse 190, CH-8057 Zurich, Email: daniel.henke@geo.uzh.ch

In the context of climate change and sea level predictions (Solomon, 2007; Raper, 2006), natural hazard prevention and water management (Purkey, 2009) the retention of water in glaciers is a key factor. In traditional approaches, the ice thickness of glaciers is either roughly approximated by extrapolating field measurements (drilling or Ground Penetrating Radar) or by a set of empirical (Maisch, 1982) or physically based relationships as e.g. mass conservation and principles of ice flow dynamics (Farinotti, 2009). In recent years, remote sensing in general (Huggel, 2003) and SAR specifically (Prats, 2007) contributes to precise large-scale measurements of glacier parameters. However, these methods are all restricted to the top layer of the glacier and information about its volume can only be derived indirectly from methods described above. In this paper, we present preliminary results of a 3D-SAR processing approach using low-frequency radar waves capable of penetrating the glacier ice up to a certain depth. 3D-SAR in other applications has been shown to provide accurate height estimates using techniques ranging from interferometry (Ulander, 1996) and cross correlation in circular tracks (Oriot, 2008) to tomographic processing of dual-pol data (Frey, 2008). However, the data for this study come from a campaign with a low-frequency SAR system (i.e. CARABAS sensor operating at center frequency of ~50 MHz) in 2003 over the Aletsch Glacier area, Switzerland, and were originally not acquired for 3D applications. Based on only these few, arbitrary flight tracks a method to calculate the height of the maximal backscattering response in the glacier ice and to approximate its volume was developed demonstrating the potential of SAR for mapping glacier volumes.

To generate a 3D estimate of the glacier bed, first a 3D reconstruction grid matrix is initialized with the Digital Elevation Model (DEM) values at the top layer in z-direction. Then for each flight track a 3D time-domain back-projection algorithm calculates for each voxel an intensity value as a standard 2D back-projection algorithm (Frey, 2005) does it for each pixel. We introduce an additional processing step to account for the refractivity of the glacier ice. Consequently, at each radar pulse of the flight track the points of entry at the glacier surface have to be determined. We make use of the spatial and temporal interrelationship between adjusted pixels to achieve computational efficiency. The absolute values of the resulting 3D-matrices for each flight track are multiplied to incoherently merge the single track results to one voxel image. For the common and generally more precise coherent adding the number of tracks and the orientation of the flight pattern are not appropriate. The maximal value in each z-column of the final, merged matrix corresponds to the maximum backscattering response of the radar signal and thus indicates the height of a potential glacier bed. Finally, we apply a low-pass filter to suppress noise effects and get a smooth, more realistic estimate of the surface.

This method was applied to a 5x5 km^2 test site over the Konkordiaplatz with a horizontal resolution of 5m and a vertical resolution of 15m. Results are illustrated in Fig. 1. While for the snow and ice free surface (e.g. mountain tops) the highest backscattering response can be found in the top layers, in the glacier ice the low-frequency radar waves penetrate into the ice. It still has to be investigated whether the backscattering maxima is indeed caused by the bedrock or by other factors like a significant amount of moraine material, an unfavorable combination of crevasses, processing artifacts or poor signal-to-noise ratio.

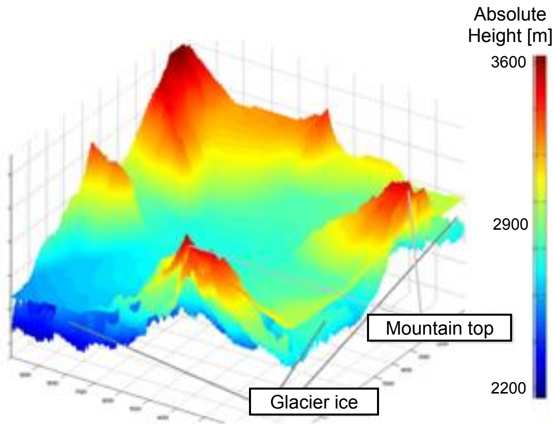

Fig. 1: DEM and 3D-SAR surface maps.

The results demonstrate the capability of low-frequency SAR sensors to potentially map glacier volumes in a large scale. Further campaigns with a flight track pattern optimized for the problem of 3D glacier mapping, and more research including ground truth validation, has to be done to verify the results. These ground truth validations are especially relevant to the question of how accurate the estimated height of the maximal backscattering is and how it is influenced by simplified physical assumptions and estimated processing parameters.

References

Farinotti D., M. Huss, A. Bauder, and M. Funk, "An estimate of the glacier ice volume in the Swiss Alps," *Global and Planetary Change*, vol. 68, pp. 225-231, 2009.

Frey O., E. Meier, and D. Nüesch. “A Study on Integrated SAR Processing and Geocoding by Means of Time-Domain Backprojection,” *International Radar Symposium IRS 2005*, vol. 1, pp. 645-649, 2005.

Frey O. and E. Meier, “Tomographic Focusing by Combining Time-Domain Back-Projection and Multi-Looking Based Focusing Techniques,” *European Conference on Synthetic Aperture Radar*, Friedrichshafen, Germany, 2008, vol. 2, pp. 73-75.

Oriot H. and H. Cantalloube, “Circular SAR imagery for urban remote sensing,” *European Conference on Synthetic Aperture Radar*, Friedrichshafen, Germany, 2008, vol. 2, pp. 205-208.

Purkey, D. R. and M. Escobar, “Climate Change, Glaciers, and Water Management in the Rio Santa Watershed, Peru”, *American Geophysical Union*, Fall Meeting, 2009.

Raper S. C. B. and R. J. Braithwaite, “Low sea level rise projections from mountain glaciers and icecaps under global warming,” *Nature*, vol. 439, pp. 311-313, 2006.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Ulander L. and P. Frölind, “Ultra-Wideband and Low-Frequency SAR Interferometry,“ *International Geoscience and Remote Sensing Symposium*, Lincoln, USA, 1996, vol. 1, pp. 668-670